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P01/7700 0.00-0303150.7  
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2. Patent application number

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1... Limited

St John's Innovation Centre  
Cowley Road  
Cambridge CB4 0WS

08565509001

Patents ADP number *(if you know it)*

If the applicant is a corporate body, give the country/state of its incorporation

England

4. Title of the invention METHOD AND APPARATUS FOR MANUFACTURING CERAMIC DEVICES

5. Name of your agent *(if you have one)*

Akram K. Mirza

"Address for service" in the United Kingdom to which all correspondence should be sent *(including the postcode)*

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St John's Innovation Centre  
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Patents ADP number *(if you know it)*

088433K7001

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Country

Priority application number  
*(if you know it)*

Date of filing  
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7. If this application is divided or otherwise derived from an earlier UK application, give the number and the filing date of the earlier application

Number of earlier application

Date of filing  
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8. Is a statement of inventorship and of right to grant of a patent required in support of this request? *(Answer 'Yes' if*

a) *any applicant named in part 3 is not an inventor, or*  
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YES

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Continuation sheets of this form	0
Description	8
Claim(s)	4
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Drawing(s)	6

10. If you are also filing any of the following, state how many against each item.

## Priority documents

## Translations of priority documents

Statement of inventorship and right to grant of a patent (Patents Form 7/77)

Request for preliminary examination and search (Patents Form 9/77)

Request for substantive examination (Patents Form 10/77)

Any other documents  
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11.

I/We request the grant of a patent on the basis of this application.

Signature

Date 12-FEB-2003

12. Name and daytime telephone number of person to contact in the United Kingdom

Akram K. Mirza

01223-422290

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## METHOD AND APPARATUS FOR MANUFACTURING CERAMIC DEVICES

## FIELD OF THE INVENTION

5 This invention relates to a method and apparatus for manufacturing curved elements of electro-active material. More particularly, it relates to a method and apparatus for manufacturing twice-coiled or super-helical electro-active actuators.

10

## BACKGROUND OF THE INVENTION

15 Comparably large translation displacements have been recently achieved by using a helical structure of coiled piezoelectric tape. Such twice-coiled or "super-helical" devices are found to easily exhibit displacement in the order of millimetres on an active length of the order of centimetres. These structures and variations thereof are described, for example, in the published international patent application WO-0147041 or by D. H. Pearce et al in : Sensors and Actuators A 100 (2002), 281 -

20 286.

25 These structures are ceramic devices of complex curved shape and are currently manufactured using inefficient low output methods which rely heavily on human labor. Other methods using extrusion processes are described for example in the international patent application WO-02103819. However the described process may not be feasible for all configurations of super-helical actuators.

30 Therefore it is seen as an object of the invention to provide a method and apparatus for manufacturing twice coiled actuators with limited human involvement and using flat ceramic tape as base material.

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## SUMMARY OF THE INVENTION

According to an important aspect of the invention, there is  
5 provided a method of and an apparatus for manufacturing  
ceramic devices including the steps of transporting ceramic  
tape in a green state into the proximity of a first forming  
10 element; fixing a first end of the tape with respect to the  
first forming element; moving the tape and first forming  
element relatively to each other in a motion including  
simultaneously rotational and translational movements, thus  
winding the tape around the first forming element; removing  
the fixing of a first end thereby allowing separation of the  
15 tape and first forming element to generate a helically wound  
pre-formed tape; fixing at least one end of the pre-formed  
tape with respect to a second forming element; and moving the  
pre-formed tape and second forming element relatively to each  
other in a motion including at least a rotational movement,  
thus winding the pre-formed tape around the second forming  
20 element.

The invention preferably includes the step of and devices for  
moving the tape and the first forming element relatively to  
each other including the step of continuously pressing during  
25 the movement the tape onto the first forming element at a zone  
where the tape first contacts the first forming element.

Furthermore the invention preferably includes the step of  
exerting a force on the edge of the tape at a zone where the  
30 tape first contacts the first forming element to prevent  
slippage of the tape relative to the first forming element.

The invention preferably includes the step of and devices for  
closing a second clamping element around the first end of the

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tape before releasing a first clamping element fixing the tape to the first forming element.

5 Preferably, the clamping elements used for gripping the tape or other devices designed to exert pressure directly onto the tape are pneumatically operated or spring-loaded to simulate a "tactile" handling of the tape.

10 The invention preferably includes the step of and devices for passing the first forming element along an edge holding back the pre-formed tape.

15 Preferably the pre-formed tape is held at both ends using clamping elements with one of the clamping elements fixing one end of the pre-formed tape with respect to the second forming element while the other clamping element performs a rotational movement around the second forming element.

20 The invention preferably includes the step of and devices for removing the fixing with respect to the second forming element and transferring the wound pre-formed tape onto a support structure; and placing the support structure into heated environment for drying and/or sintering.

25 The present invention is particularly advantageous used to manufacture twice-coiled helices, particularly twice-coiled actuators of piezoelectric material.

30 These and other aspects of inventions will be apparent from the following detailed description of non-limitative examples making reference to the following drawings.

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## BRIEF DESCRIPTION OF THE DRAWINGS

In the drawings:

5 FIG. 1 is a perspective view of a twice-coiled actuator as known;

FIG. 2 illustrates a first forming step in accordance with an example of the present invention;

10 FIG. 3A illustrates a step of releasing pre-formed tape from a first forming element;

FIG. 3B illustrates a second forming step in accordance with an example of the present invention; and

15 FIG. 4 illustrates the transfer of formed tape onto a support structure for drying.

20

## DETAILED DESCRIPTION

In FIG. 1, there is shown a known actuator of the twice coiled or super-helical type described in the above-mentioned WO-0147041 and Sensors and Actuators A 100 (2002), 281 -286.

25

The actuator 10 has a curved portion 12 of bimorph tape 11 that is wound helically around a first axis 13 referred to as the minor axis. For illustration, the minor axis is shown as a dashed line 13 in FIG. 1. The helically wound portion is further coiled into a secondary winding of about three quarters of a complete turn. The axis 14 of this secondary winding is referred to as the major axis and shown as a small dashed circle 14 with a central solid point again to facilitate description and illustration. The first winding is

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known as the primary winding or primary helix. The secondary winding could exceed one turn and form a spiral or secondary helix. It is therefore usually referred to as secondary helix, even though shown in the examples herein as three-quarter winding only. When used as an actuator, one end 111 of the tape 11 is fixed to a moveable object (not shown) while the other end 112 of the tape 11 is mounted onto a base plate 15.

5 The manufacture of the actuator 10 from a precursor ceramic tape is a very complex task usually performed by manual labor. It involves the steps of slowly winding a helix of the tape around a cylindrical rod and, and after carefully removing the rod, placing the helix into a "sagger" that supports the helix in its coiled form during subsequent drying until the ceramic 10 tape is sufficiently stiff to support its own weight. The coiled helix is then burned to remove binder and other organic 15 components and sintered to form the ceramic actuator.

20 While the above steps can be performed manually, the process does not readily lend itself for automation. The properties of 25 the precursor ceramic tape are such that, though pliable, it slackens readily and is unable to support its own weight.

Referring now to FIG. 2A, there is shown a conveyor system 20 that transports a strip of precursor ceramic tape 21 to a cylindrical rod 23. The conveyor system 20 includes rollers 201 and support surfaces 202 that guide the strip 21 close to the former 23. A smoothly contoured surface 204 directs the tape 21 under the rod 23. After a tap 211 of sufficient length 30 has passed a first pneumatically operated clamp 241 closes and fixes the tape 21 against the rod 23. Then the rod 23 rotates as indicated, while more tape is pushed through the conveyor system 20.

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The rod 23 acts as a primary or first former. Its diameter is chosen such that it matches the inner diameter of the primary helix. When positioned at the conveyor system, an end block 231 supports the distal end of the rod to prevent it from bending.

5 The conveyor and the axis of the rod form an acute angle to feed tape at this angle onto the rod. As the strip is pushed by the conveyor across the rod, the rotation of the rod 23 causes the strip 21 to be wound around it. Simultaneously with the rotation, the rod 23 is moved in direction of its axis. Both motion are synchronised such that the tape is wound around the rod in a helical manner.

10 15 In FIG. 2B, the winding process of FIG. 2A is shown at a later stage with the tape 21 being wound around the former 23 for approximately half of its length. As the first clamp 241 is retracted from the conveyor system 20, a second spring-loaded clamp 242 is brought from below into contact with the tape. The second clamp has a slightly concave surface with a stop pin 243. The concave surface maintains pressure on the tape while the stop pin 243 prevents the slippage of tape along the rotating rod 23, thus ensuring that the helix remains tightly wound.

20 25 After the strip of tape 21 is fully wound around the primary former 23, the second end of the tape forms a second short stub (not shown) similar to the stub 211. The primary former 23 is then moved to a second forming element. During the transport both clamps 241, 242 remain in place.

30 At the location of the second former 33, two clamps 351, 352 grip the tape at the stubs 211 as illustrated in FIG. 3A. The previous clamps 241, 242 are released and the forming rod 23

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is moved in axial direction in sliding contact with an edge 353. The first former 23 is shown as a dashed outline. The first clamp 351 is fixed to the mounting block 331 that carries the second former 33. It pushes the stub 211 at one end of the tape 21 against the outer edge of the inner cylinder 332 of the second former 33. The combined clamp 351 and second former 33 are simultaneously rotated around the center axis of the cylindrical second former 33 and moved towards the second clamp 352 that rests immobile during this movement. As the second former approaches the second clamp, more of the rod 23 slides over an edge 353 and more windings are pushed from the distal end of the rod. The windings are wound around the inner cylinder 332 of the rotating secondary former 33 until the tape is completely stripped of the primary former. At this stage, which is illustrated in FIG. 3B, the pre-formed tape 21 is wound completely around the inner cylinder 332 of second former 33 and held in place by the two clamps 351, 352.

20 The inner cylinder 332 is spring-mounted within a bore of an outer cylinder 333 of the second former 33, such that pressure on the front face of the inner cylinder causes it to retract into the bore while the advancing sleeve of the outer cylinder pushes the wound tape 21 from the former.

25 At this stage of the process the twice-coiled actuator of FIG.1 is completed in its "green" state. However to stabilize the structure, the tape 21 has to be at least dried. To free the second former 33, the wound helix is transferred into a tray or array for further handling off-line .

30 In FIG. 4, the secondary former 33 is shown approaching a array 40 of saggers 41. As the secondary former meets a sagger 41, the front face of its inner cylinder 332 (shown in FIG. 3

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above} engages a matching cylinder 431 within a recess area 432 of a sagger 41. As the secondary former moves closer to a sagger, the spring-loaded inner cylinder 332 remains stationary and the outer ring 333 pushes the twice-coiled 5 helix into the recess 432 of the sagger. The clamps that grip the stubs or ends of the tape open to release the helix. The outer boundary of the recess area 432 has a diameter that closely matches the nominal outer diameter of the major helix of the actuator. The edges of the boundary of the recess area 10 are contoured or chamfered to assist the placing of the tape into the sagger. The sagger array 40 filled with fully formed green tape is then placed in a heated environment for drying and prepared for further processing stages such as sintering in an oven.

15

The various clamping devices described above are using pneumatically operated actuators commercially available for example from Festo. Commercially available DC servo motors are used to generate other movements of the components. All 20 components are under the control of a computer program stored in and executed from an Intel processor based workstation.

Variations of the above example are readily within the scope 25 of a skilled person. It is for example feasible to design the forming elements in a segmented manner to alter their diameter and hence the dimensions of the actuator. It is also possible to replace the second forming element with a removable sagger and thus wind the pre-formed tape directly onto the sagger.

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## CLAIMS

1. Method of manufacturing a ceramic device comprising the steps of

5 - transporting ceramic tape in a green state into the proximity of a first forming element;

- fixing a first end of said tape with respect to said first forming element;

- moving said tape and first forming element relatively to each other in a motion including simultaneously rotational and translational movements, thus winding

10 said tape around said first forming element;

15 - removing said fixing of a first end thereby allowing separation of said tape and first forming element to generate a helically wound pre-formed tape;

- fixing at least one end of said pre-formed tape with respect to a second forming element; and

- moving said pre-formed tape and second forming element relatively to each other in a motion including at least a rotational movement, thus winding said pre-formed tape around said second forming element.

2. The method of claim 1 wherein the step of moving said tape and first forming element relatively to each other includes the step of continuously pressing during said movement said tape onto said first forming element at a zone where said tape first contacts said first forming element.

30 3. The method of claim 2 further comprising the step of exerting a force on the edge of the tape at a zone where said tape first contacts the first forming element to prevent slippage of said tape relative to said first forming element.

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4. The method of claim 1 wherein the step of removing said fixing of a first end includes the step of closing a second clamping element around the first end of the tape before releasing a first clamping element.

5. The method of claim 1 wherein the step of separating said tape and first forming element includes the step of passing the first forming element along an edge holding back the pre-formed tape.

10

6. The method of claim 1 wherein the pre-formed tape is held at both ends using clamping elements with one of said clamping elements fixes one end of said pre-formed tape with respect to the second forming element while the other clamping element performs a rotational movement around said second forming element.

15

7. The method of claim 1 further comprising the steps of

20

- removing the fixing with respect to the second forming element and transferring the wound pre-formed tape onto a support structure; and
- placing said support structure into environment for drying.

25

8. The method of claim 1 wherein the tape is handled by pneumatically operated devices.

9. Apparatus for manufacturing a ceramic device from tape

30

in a green state comprising

- a first forming element;
- a first clamping system for fixing a first end of said tape with respect to said first forming element;

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- motors for moving said tape and first forming element relatively to each other in a motion including simultaneously rotational and translational movements, thus winding said tape around said first forming element to form a preformed tape;
- a second forming element;
- a second clamping system for fixing at least one end of said pre-formed tape with respect to said second forming element; and
- motors for moving said pre-formed tape and second forming element relatively to each other in a motion including at least a rotational movement, thus winding said pre-formed tape around said second forming element.

15

10. The apparatus of claim 9 wherein the first clamping system includes a spring-loaded surface that in operation continuously presses the tape onto said first forming element at a zone where said tape first contacts said first forming element.

20

11. The apparatus of claim 10 wherein the spring-loaded surface is combined with a force-transmitting member adapted to contact the edge of the tape at a zone where said tape first contacts the first forming element to prevent slippage of said tape relative to said first forming element.

25

12. The apparatus of claim 9 comprising a stripping edge making contact to the first forming element to separate said first forming element and the pre-formed tape.

30

13. The apparatus of claim 9 comprising a second clamping system.

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14. The apparatus of claim 13 wherein second clamping system includes a first clamping element for fixing a first end of the tape to a second forming element and a second clamping element adapted to perform a rotational motion around said second forming element.

5

15. The apparatus of claim 13 further comprising one or more saggers having recesses adapted to support the formed tape during drying.

10

16. The apparatus of claim 9 wherein the clamping devices are pneumatically operated.

15

17. A ceramic structure made using methods or apparatus in accordance with any of preceding claims.

18. A electro active ceramic structure made using methods or apparatus in accordance with any of preceding claims.

20

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## ABSTRACT

5 A method and apparatus is described for forming complex ceramic structures, particularly piezoelectric super-helical structures, including the steps of feeding a ceramic tape around a first former to form a pre-formed tape and while gripping the ends of said pre-formed tape separating the first former from the pre-formed tape and guiding the preformed tape around a second former and placing the twice-formed tape onto 10 a support for heating.

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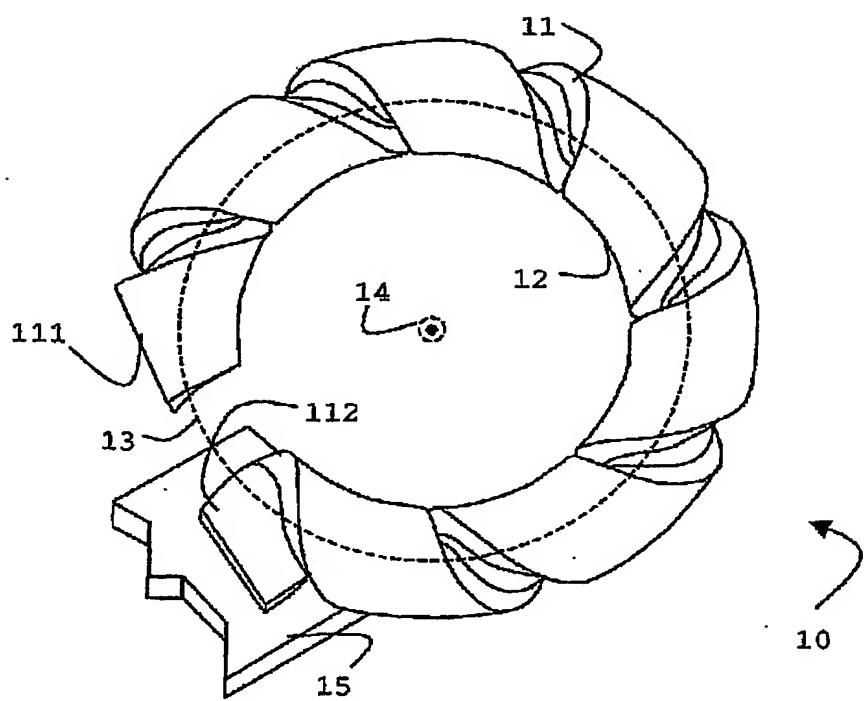


FIG. 1 (Prior Art)

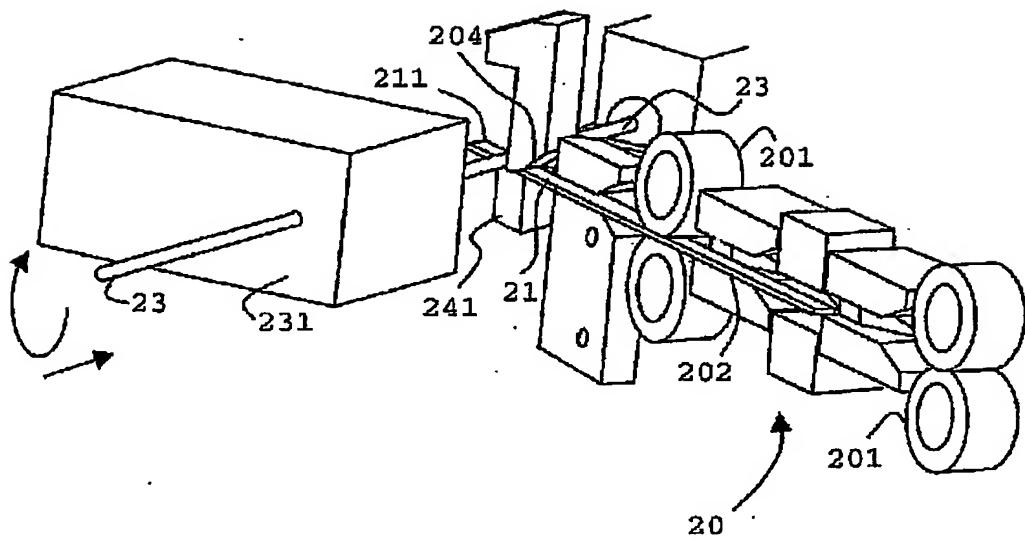


FIG. 2A

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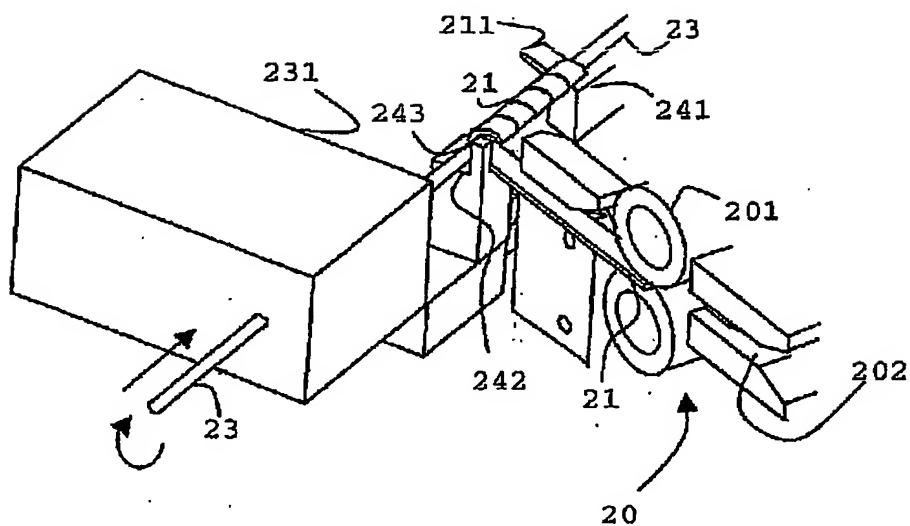


FIG. 2B

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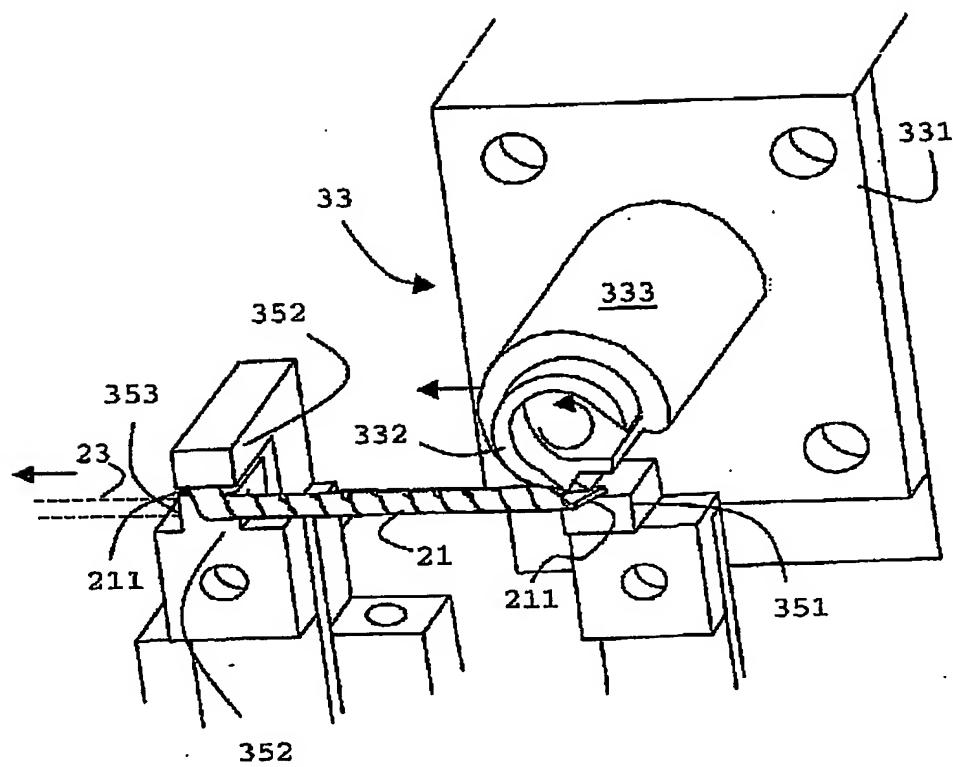


FIG. 3A

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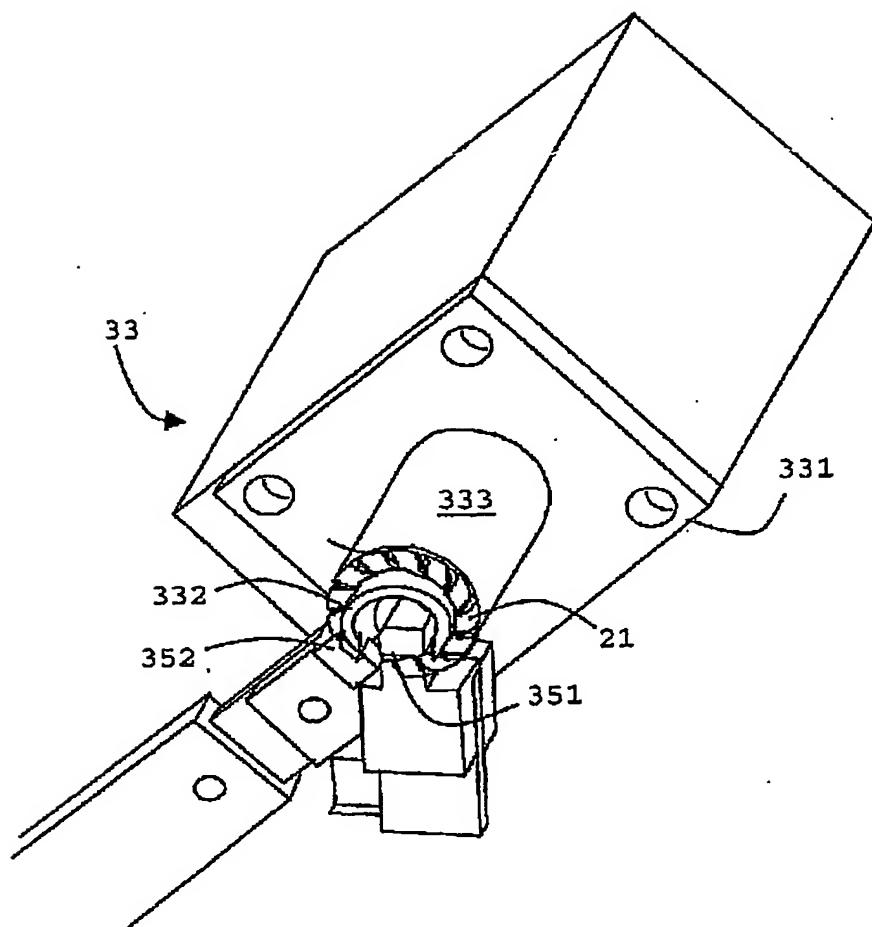


FIG. 3B

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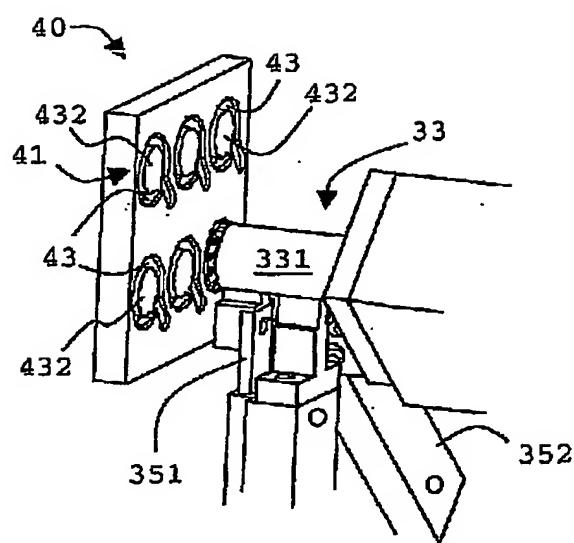


FIG. 4

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